Research Article

Topographical and Tribological Characteristics of Asian Human Hair Cuticles

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Received 23 September 2014; Accepted 26 December 2014

Academic Editor: Mo Li

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The topography and frictional force of Asian black male and female hair cuticles at different locations are determined using atomic force microscopy (AFM) and friction force microscopy (FFM). The frictional values, mapped for comparison with surface morphology, corresponded qualitatively with the structures' plane surface characteristics. The results indicate that the hair surface was damaged and modified at different temperatures and heating times. The height of the female hair at a blowing temperature of 60°C after a duration of 2 min between the cuticle edge and cuticle surface was approximately 440–556 nm. The adhesion phenomenon occurs on the hair surface and interface. The cuticles do not vary after the heating; however, the hair damage sustained increases with serious deterioration.

1. Introduction

Human hair is a natural fiber with an exceedingly complex structure [1]. The human hair surface comprises three layers, an outer cuticle layer, a middle cortex layer, and an inner medulla layer. The cuticle layer comprises a cuticle and a cell membrane complex with intercalated flattened cells. The medullary layer of the hair shaft consists mainly of the cortical layer and the epidermis; the hair root contains the hair follicles, hair bulb, dermal papilla, and hair matrix cells [2]. The cell membrane complex comprises a hydrophilic layer (delta-layer) and two hydrophobic layers (beta-layers) [3].

Recently, the surface and structure of human hair have been studied using various techniques, such as scanning electron microscopy (SEM) [4] and transmission electron microscopy (TEM) [5]. Atomic force microscopy (AFM) has now proven to be a valuable experimental tool, particularly in nanotribology, materials science, and the surface science. Frictional force microscopy (FFM) is a useful tool for providing nondestructive measurement of hair fiber and cuticular surfaces [6]. Bhushan [7] studied nanoscale characterization of the cellular structure, mechanical properties, and

morphological, frictional, and adhesive properties of hair. Seshadri and Bhushan [8] studied the tensile deformation properties of Caucasian virgin damaged hair samples. Sadaie et al. [9] employed frictional force microscopy with a self-assembled monolayer (SAM) modified probe to understand the frictional properties of the hair surface.

This study investigates the nanomechanical properties of human hair using AFM and FFM. The topography and images of Asian female and male hair cuticle surfaces at different locations are presented. The blowing temperature on the surface morphology, microstructures, and frictional force of female hair cuticles are also explored.

2. Methodology

Asian black virgin hair samples were used without any chemical treatment. The samples were washed with distilled water before use to reduce the number of deposits. The cleanest hair sections located near the roots were selected. The hair sample was collected from the scalp from an approximately 1 mm uniform test site to the right of the hair; hair detection was performed at room temperature.

FIGURE 1: (a) Schematic of hair fiber microstructure and (b) scanning electronic microscope image of hair cuticle surface.

Using the original contact atomic force microscope, the distribution of the frictional force was measured using a Bruker commercial AFM system in contact mode with a silicon tip. The AFM was equipped with a top-view optical microscope. The scanning rate was approximately 1.5 Hz, and the scan range was approximately 10 μm. The AFM was operated in a laboratory controlled to a temperature of approximately 22°C and a relative humidity of approximately 50%.

The surface roughness of the hair surfaces can be obtained by determining the root mean square average (RMS) roughness in vertical direction [10, 11]. The RMS is defined as follows:

$$\text{RMS} = \sqrt{\frac{1}{n} \sum_{i=1}^n z_i^2}, \quad (1)$$

where z_i is the surface profile and n is the total number of pixels in the profile dimension.

3. Results and Discussion

Figure 1 shows the hair fiber structure. In Figure 1(a), the hair fiber is divided into three layers: the epidermis, cortex, and medulla layer. In the first layer, the main function of the epidermis is to protect the hair inside and to resist external stimuli. In the second layer, the cortical layer is mainly concerned with the physical and chemical properties but also determines the main layer of the hair color. The third layer, the medullary layer, is mainly connected to the scalp hair follicles to maintain the growth of the most important places to maintain adequate nutrition of the medullary layer such that the hair will be healthy. Figure 1(b) presents a scanning electronic microscope (SEM) image of the human hair structure.

Figure 2 presents a schematic view of an atomic force microscope force-distance curve. At point a, by the side remote from the probe surface, because there is no force acting between the object and the probe by the side, the side

FIGURE 2: Force and displacement of the probe tip-sample separations.

surface is not deformed when the probe approaches the surface side of point b. Due to the gravitational pull between the surface and the probe, the tip is bent to the side of the object; the gravitational force is adsorbed on the surface layer of the probe surface [12].

Figure 3 presents topography AFM images of Asian male and female cuticle surfaces at different locations. Figures 3(a1), 3(a2), 3(a3), and 3(a4) correspond to the eyebrow, leg, facial whiskers, and hair surfaces of Asian males, respectively. The AFM images of various hair location surfaces along with section plots are presented. The results reveal that all the cuticle cells of the male leg, facial whiskers, and hair surfaces are nearly parallel to the underlying cuticle cells. The eyebrow cuticle has a shape cuticle structure around the edge. All the cuticle cells exhibit similar angles to the hair axis and form a tile-like hair surface structure. The visible cuticle thickness of the eyebrow, leg, facial whiskers, and hair surfaces of Asian males are approximately 0.3–0.6, 0.4–0.8, 0.3–1.5, and 1.0–2.0 μm, respectively. The visible cuticle

FIGURE 3: AFM images of (a) the male and (b) female cuticle surface at different locations.

length of the eyebrow, leg, facial whiskers, and hair surfaces of Asian males is approximately 4–10, 5–12, 5–9, and 5–10 μm , respectively.

Figures 3(b1), 3(b2), 3(b3), and 3(b4) show AFM images corresponding to the eyebrow, arm, armpit, and hair surfaces of Asian females, respectively. The visible cuticle thickness of the eyebrow, arm, armpit, and hair surfaces of females is approximately 0.2–0.5, 0.1–0.5, 0.3–1.0, and 0.5–1.0 μm , respectively. The surface roughness RMS of the male and female cuticle surfaces was 9–23 nm and 8–34 nm, respectively.

The visible cuticle length of the eyebrow, arm, armpit, and hair surfaces of the female is approximately 5–10, 3–7, 5–11, and 5–8 μm , respectively. The hair cuticle edge thickness of the female is less than that of the male at different locations. LaTorre and Bhushan [4] reported similar results of the cuticle thickness and length of approximately 0.3–0.5 and 5–10 μm , respectively.

Figure 4 presents FFM images of Asian male and female cuticle surfaces at different locations for an applied load of 2 V. Here, a 1 V change corresponds to a change in the apparent applied load of 10 nN. Although the topographic FFM image was not greatly changed by the applied load, the FFM image reveals that the surface was disturbed by probe scanning. The image shows that the frictional force surfaces of the hair cuticle were related to the surface topography. The edges of the cuticular substructures of the male and female hairs were shaded. The frictional force value of the female is less than that of the male.

Figures 5(a)–5(d) present AFM images of the female cuticle surface at various temperatures for 2, 4, 6, and 10 min, respectively. The surface temperatures for blowing time durations of 2, 4, 6, and 10 min were approximately 60, 65, 70, and 75°C on the hair cuticle structures, respectively. The RMS surface roughness of the female cuticle surface at temperatures of 60°C–75°C was 8–22 nm.

Figures 6(a)–6(d) present FFM images of the frictional force distribution of the female cuticle surface at blowing temperatures of time durations of 2, 4, 6, and 10 min, respectively. Damage of the cuticle layers occurred, and the disordered structure and edges of several cuticles were corrugated after blowing temperatures of time durations of 4 min. The reason is due to the hair being delaminated after blow drying.

4. Conclusions

The properties of the human hair cuticle of Asian females and males at various locations were investigated using atomic force microscopy (AFM) and frictional force microscopy (FFM). From the microstructural perspective, the cuticles in human hair are approximately 10-scale thickness. The interfaces between the cuticle edge and cuticle layers increase the frictional force and interaction on the cuticle surface.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

FIGURE 4: FFM images of (a) the male and (b) female cuticle surface at different locations.

FIGURE 5: AFM images of (a) the female cuticle surface at different temperatures of (a) 2 min, (b) 4 min, (c) 6 min, and (d) 10 min.

FIGURE 6: FFM images of (a) the female cuticle surface at different temperatures of (a) 2 min, (b) 4 min, (c) 6 min, and (d) 10 min.

Acknowledgments

This work was partially supported by the Ministry of Science and Technology of Taiwan under NSC 100-2626-E151-003MY3. The authors would like to thank Enago (<http://www.enago.tw>) for the English language review.

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